Droplet-based EUV LPP Source for High Volume Metrology

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Presentation Outline

- ALPS Program Overview
- ALPS II Performance
- Debris and Emission Studies
- Debris Mitigation Strategy
- Source Collector Module
- Cleanliness after IF
- Alternative Fuels
- Summary & Conclusions

EUV Source Technology for Actinic Inspection

Development / Research of **droplet-based EUV LPP sources** since Jan 2007

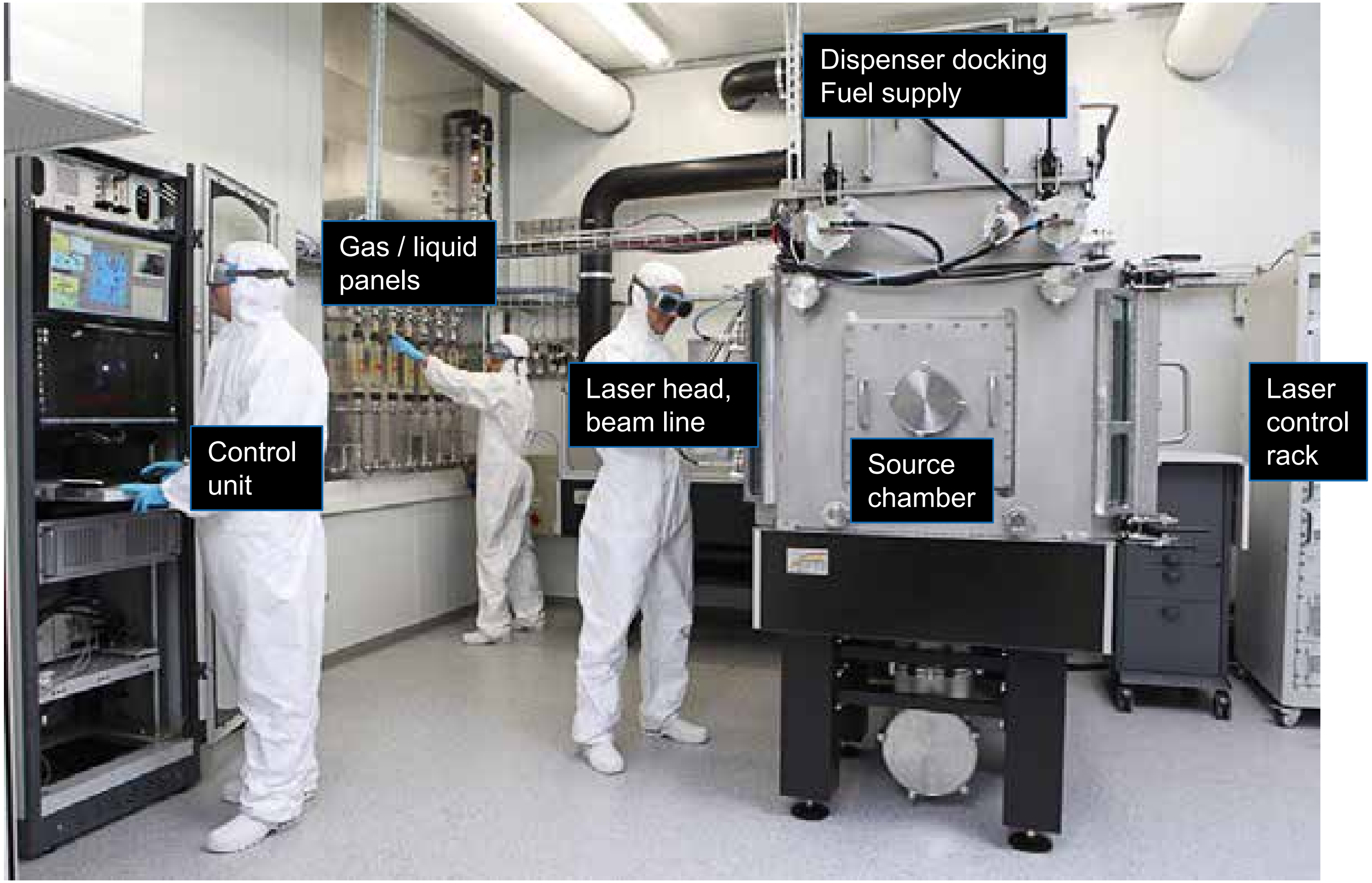
Currently, fully automated functioning system has been tested for 100's of hours of operation

Recent System level advancements:

Emission stability using droplet control in time and space	(-2013)
Characterization of source emission and debris generation	(-2014)
Debris mitigated EUV collector	**(2014)**
Cleanliness validation of tin-based LPP source after IF	**(2014)**

Long-term effort towards other wavelengths and higher power (Watt range)

ALPS II Prototype Unit Built for HVM application



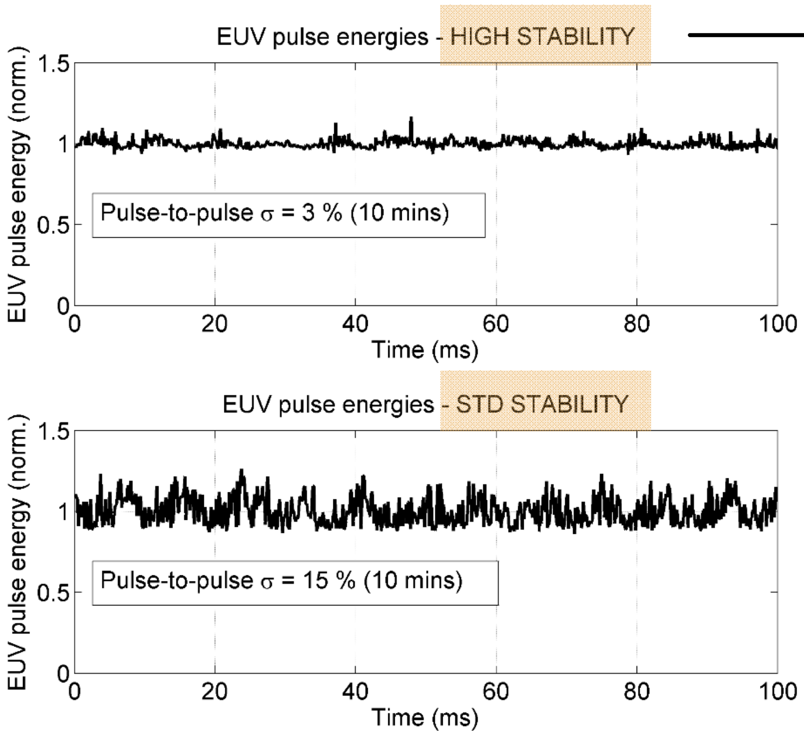
ALPS II EUV Light Source

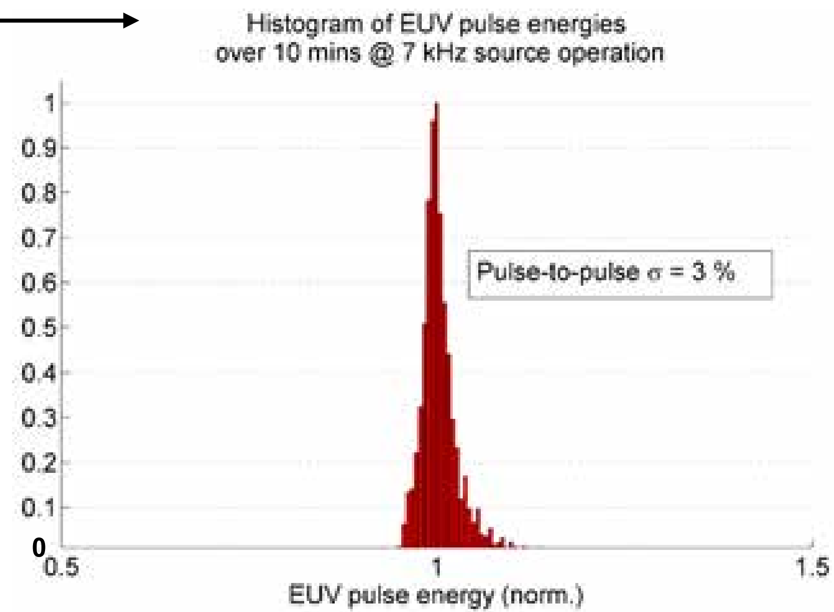
Parameters	Value
Laser power on target (W)	1600
Laser frequency (kHz)	>6
Laser focal spot size (µm)	70 (FWHM)
EUV source size (µm)	60 (FWHM)
Conversion efficiency (%)	>1%
Source power at the source (W)	>12
Source brightness (W/mm^{2}sr)	350

- Driven by DPSS Nd:YAG laser (average power of 1.6 kW, 1.064 µm, 5-20 kHz).
- Droplet dispenser with >30 µm tin droplet generation for hours of operation.
- Droplet tracking system with laser triggering on individual droplets enables droplet-laser alignment within <10% of droplet diameter.
- Full diagnostic including in-band energy monitors and out-of-band spectroscopy
- Debris mitigated grazing incidence collector, including clean IF module with imaging capability.
- Compatible with various collector configurations

EUV Emission Stability

- Integrated EUV pulse energies for 10 mins source operation
- EUV energy monitor (ML, Zr filter) and gated hardware integrator. Source operated at 7 kHz

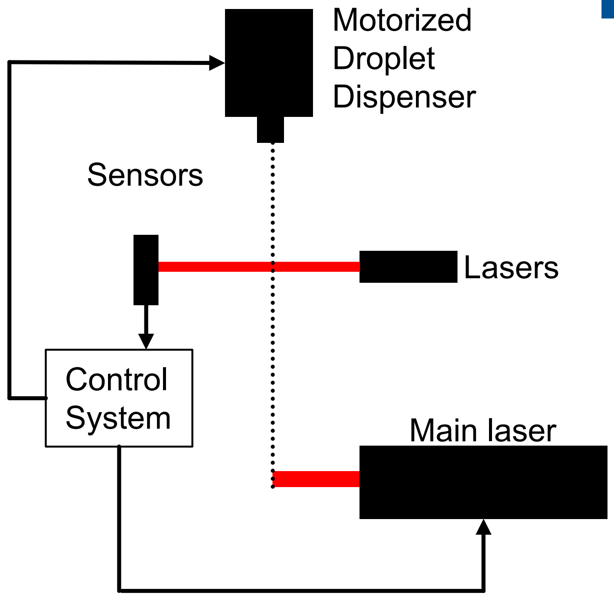


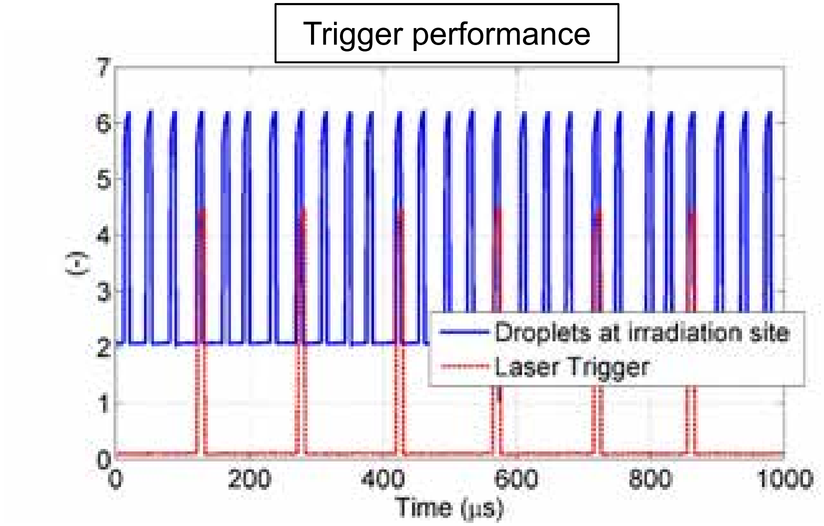


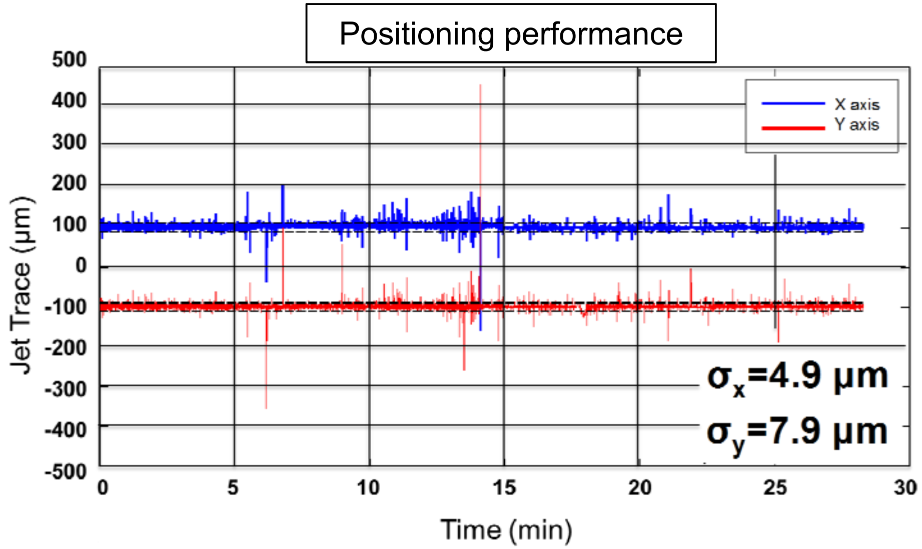
- **Pulse-to-pulse stability of EUV energy of 3% (σ)** has been achieved. **100 ms average stability is 1.29% (σ).**
- Typical EUV pulse-to-pulse stabilities are on the order of 10-15% (σ).

Droplet Tracking, Positioning & Triggering

- Compensation for low frequency lateral drifts of tin droplet train
- EUV scan function (using gated hardware integrator) included in the feedback loop
- Compensation of temporal droplet jitter by laser triggering for individual droplets after computing individual droplet passage times.







Debris Mitigation Strategy

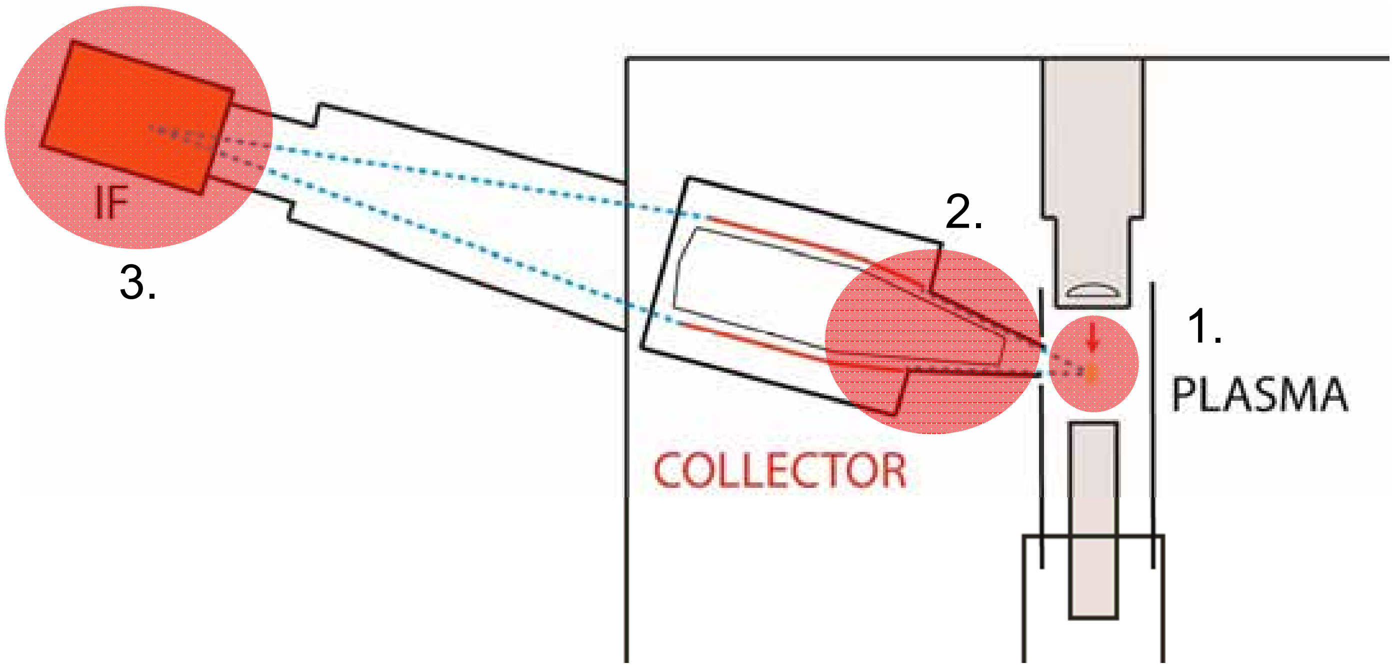
A. Limit debris formation

B. Mitigate debris

LAYER 1. Control debris around plasma

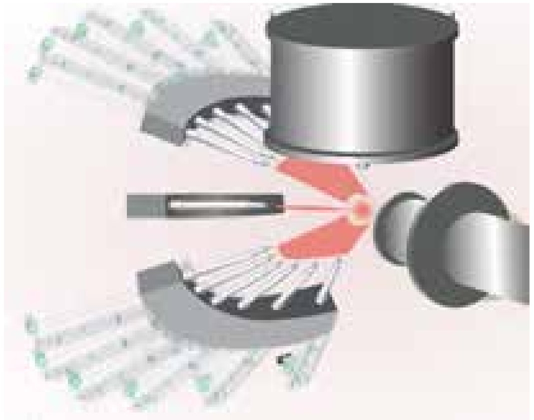
LAYER 2. Control debris in the collector module

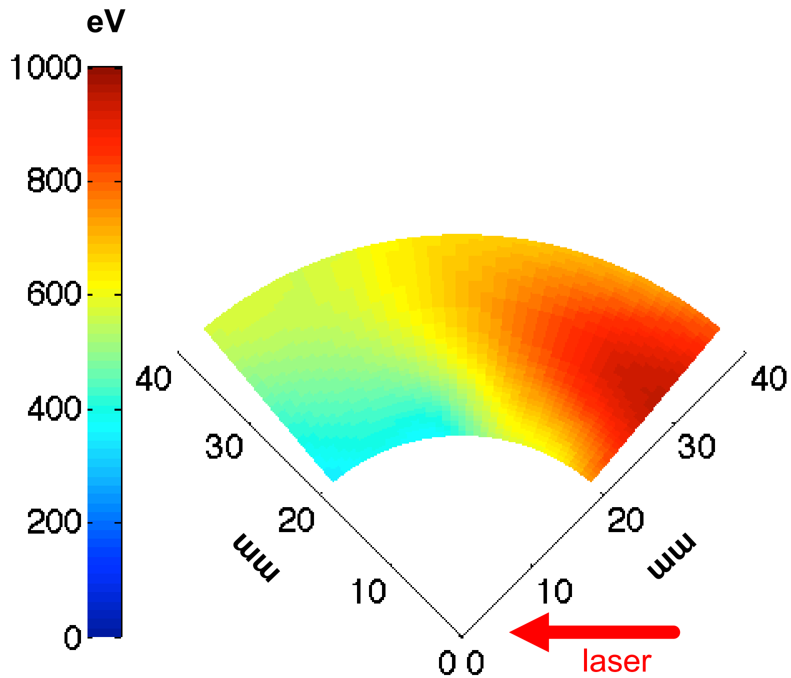
LAYER 3. Control debris at IF

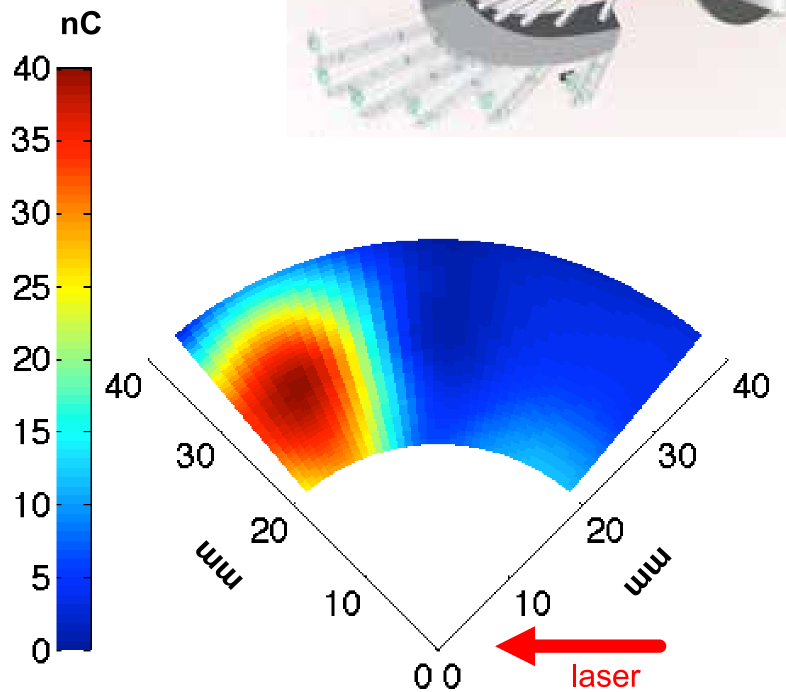


Angular Distributions of Tin ions

- Tin ion characterization using motorized array of Langmuir Probes
- Distributions of kinetic energy and charge in horizontal plane







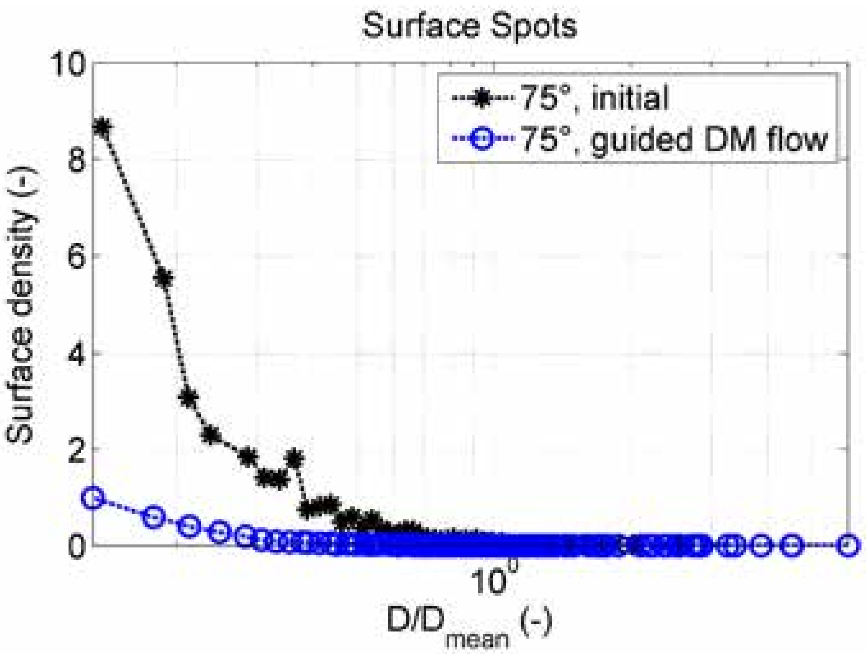
- Largest kinetic energies (damage potential) in forward direction
- Increased abundance of slow ions on the rear side of the target

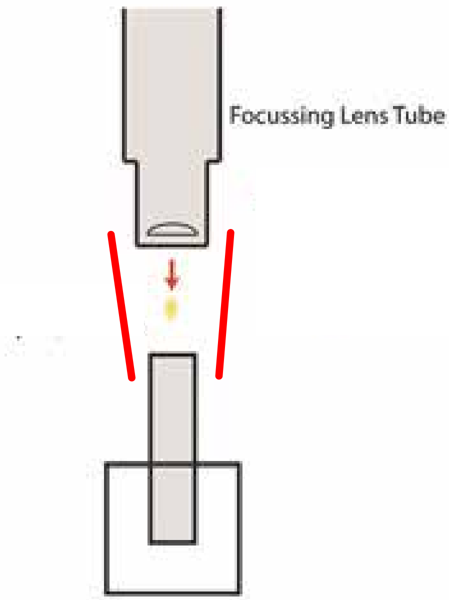
N. Gambino et. al, Rev. Sci. Instrum. 85 (9), 093302 (2014).

Debris Mitigation around Plasma Site

DM LAYER 1

- Optimized flow control and EUV transmission of debris mitigation gas around irradiation site
- Tin debris captured on Si witness plates



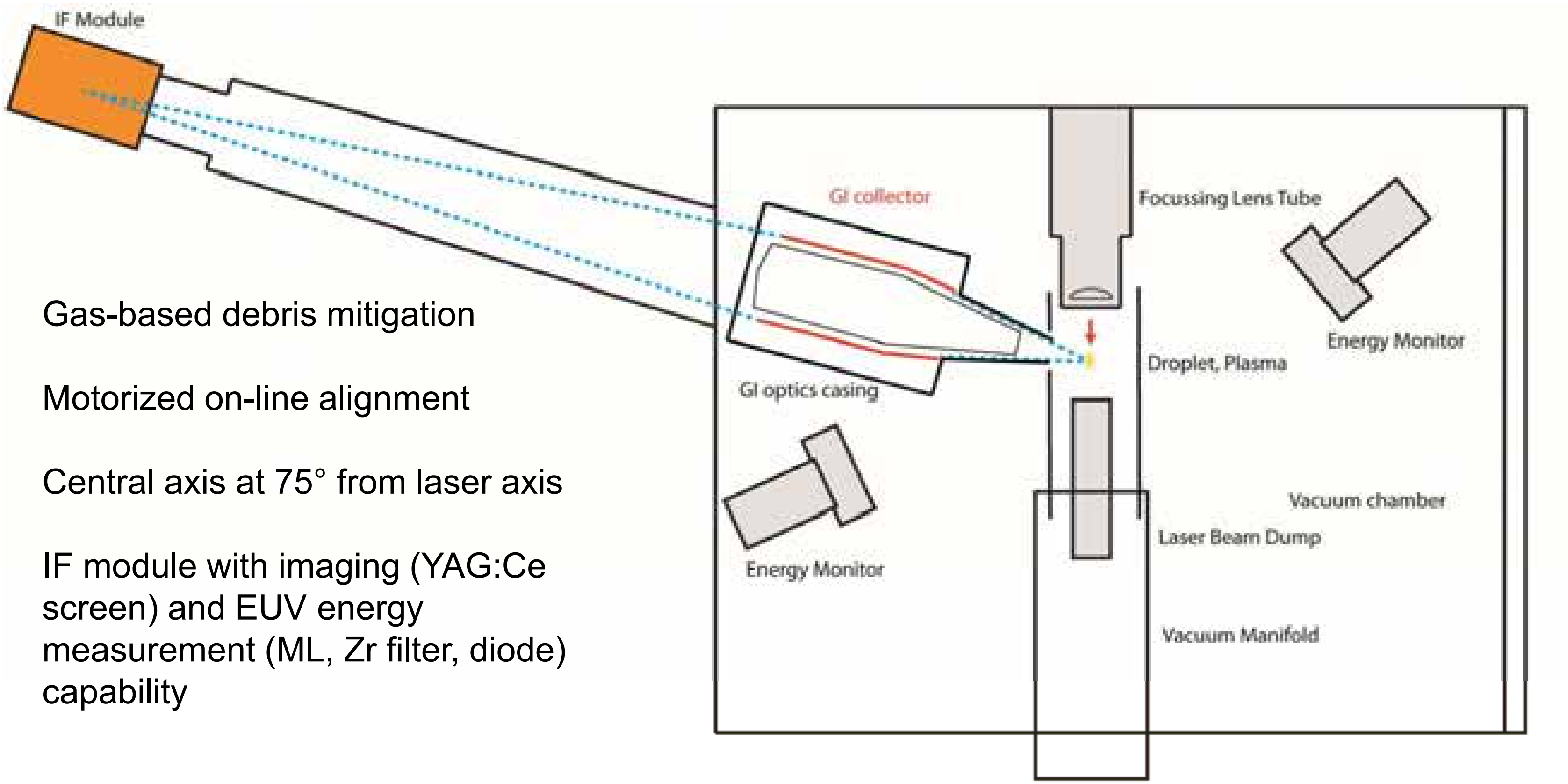


- Low energy debris is entrained by high momentum flow.
- Significant reduction (9x) of covered surface by efficiently tuning and guiding mitigation gases in the vicinity of the plasma. EUV emission is kept constant.

Source Collector Module

DM LAYER 2

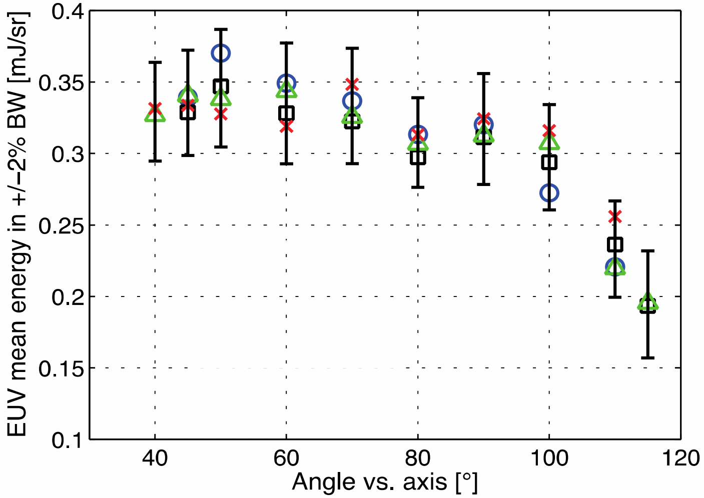
- Grazing Incidence (GI) collector for diagnostics and imaging



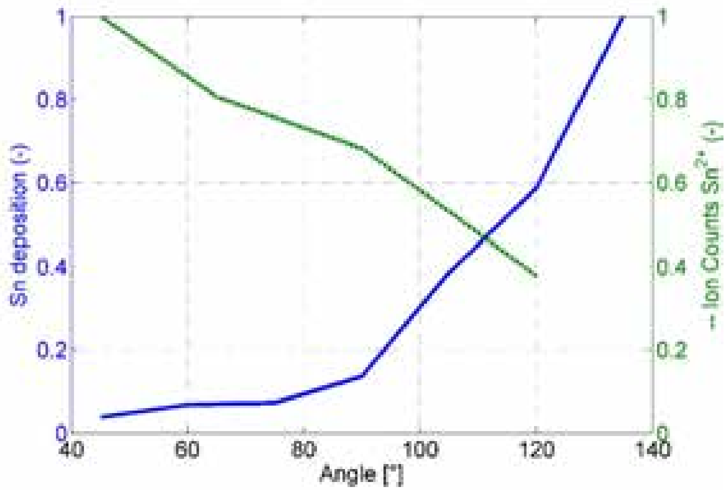
- Gas-based debris mitigation
- Motorized on-line alignment
- Central axis at 75° from laser axis
- IF module with imaging (YAG:Ce screen) and EUV energy measurement (ML, Zr filter, diode) capability

Source Collector Optimum Location

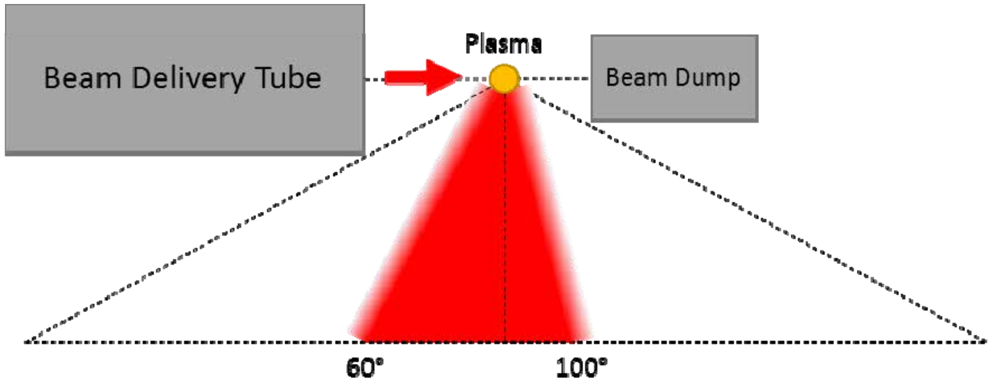
- Optimum location determined by trade-off between emission, neutral and ion debris



A. Z. Giovannini et al., J. Appl. Phys. 114, 033303 (2013).



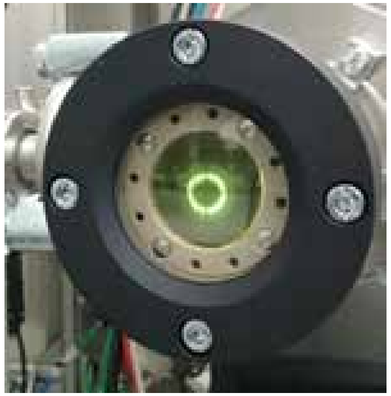
(*) Si sample exposure
(**) Results from electrostatic analyzer, Diss. ETH A.Z. Giovannini



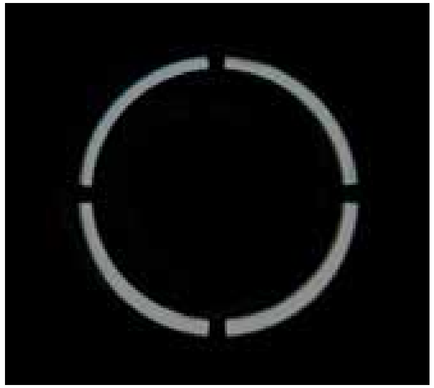
www.lec.ethz.ch/plasma

Source Collector Module - Imaging

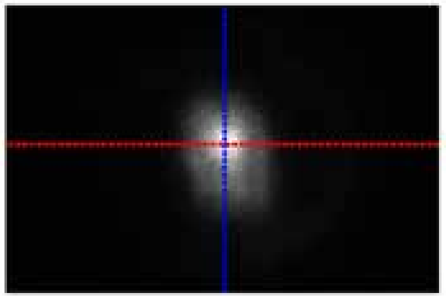
- Imaging for monitoring of alignment, collector reflectivity drop and focal spot uniformity

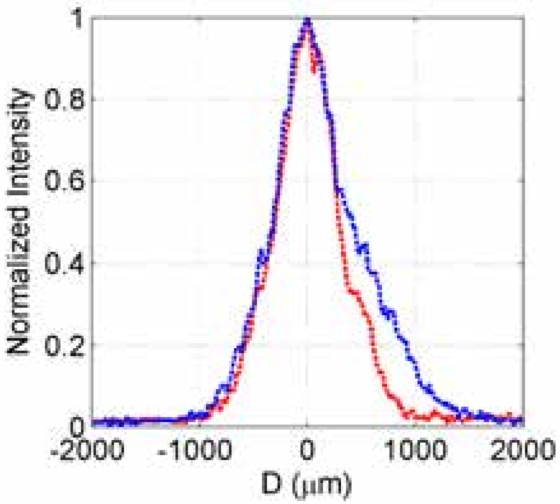


Collected EUV emission on screen



Illuminated collector



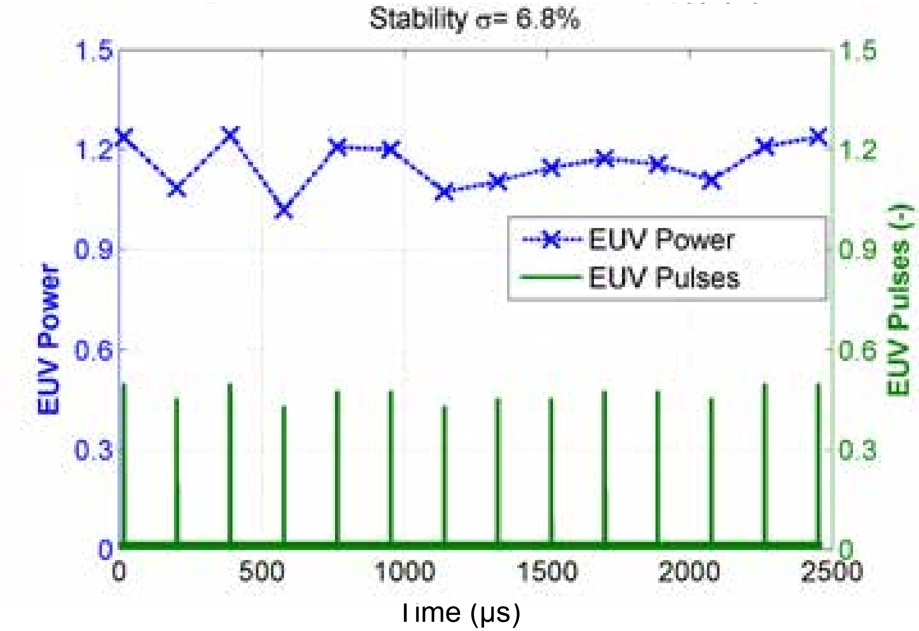


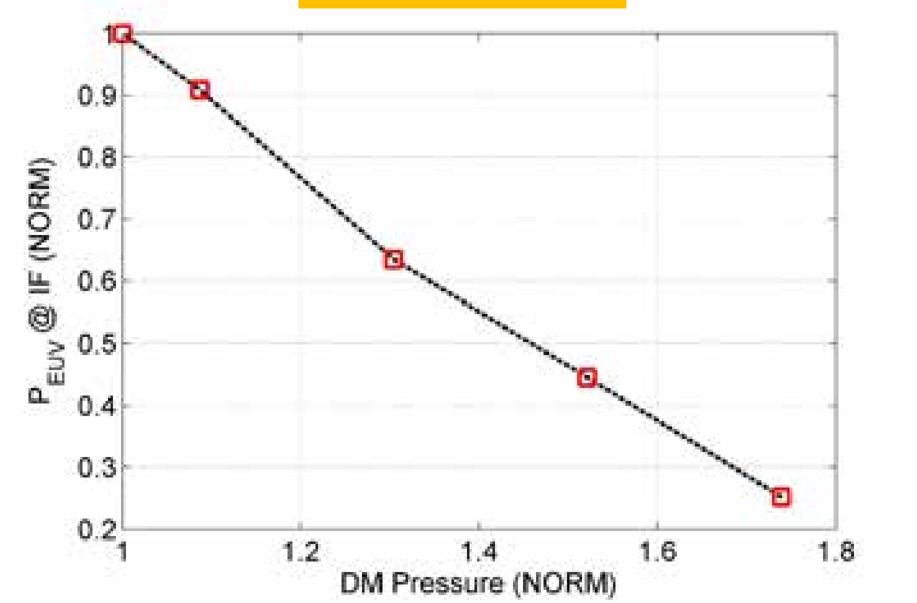
Beam uniformity close to IF (FWHM 500 μm)

Source Collector – EUV at IF

- EUV power measured by photodiode at IF after reflection from ML
- 6 kHz source operation, 50 µm tin droplets

DM LAYER 2



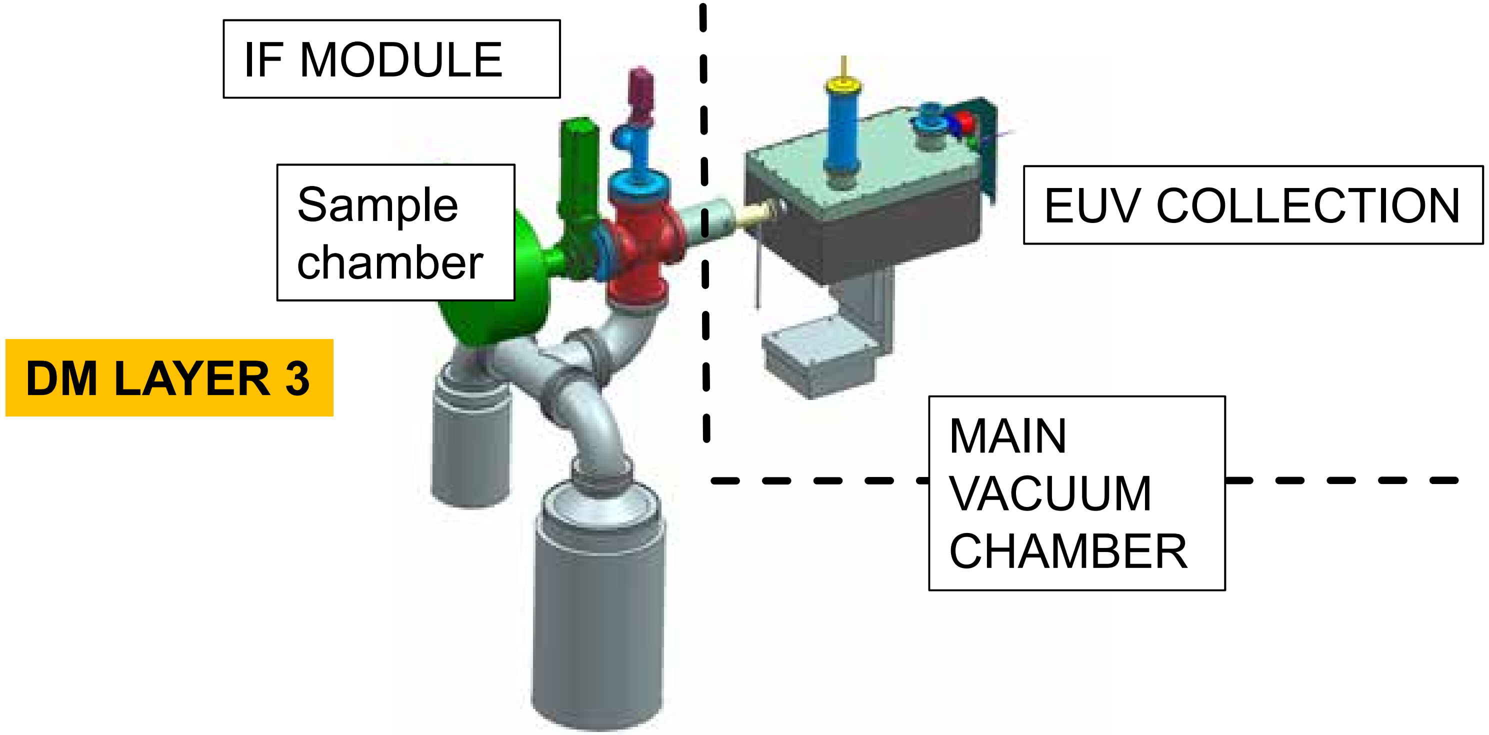


- Pulse-to-pulse stability of EUV energy of 6.8% (σ). 100 ms average EUV stability is 2.9 % (σ).
- Current setup allows studies of mitigation gas pressure with significant variations in EUV energy at IF

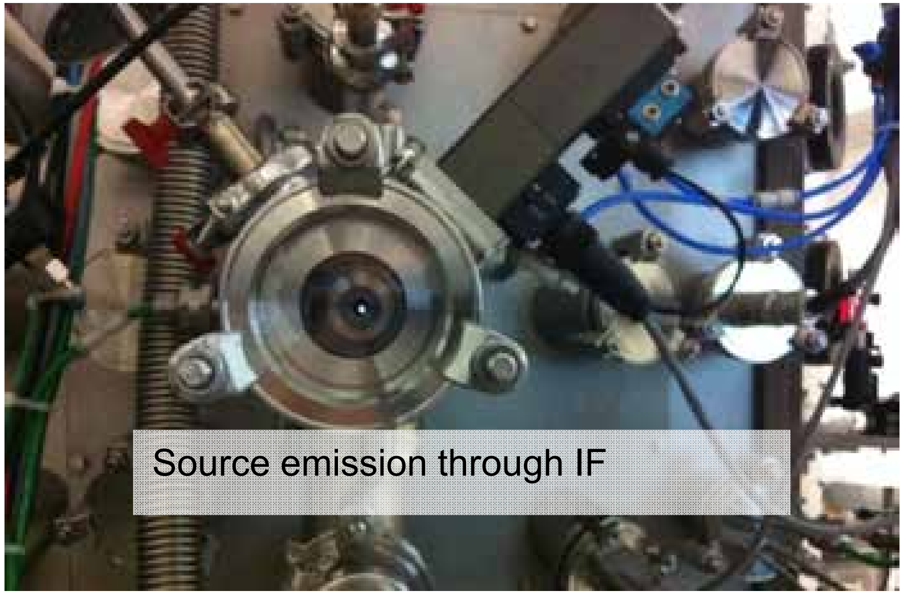
Cleanliness of Tin LPP Source after IF

- Positive assessment of IF cleanliness after 100's hours of operating time.
- Detailed quantification of IF cleanliness for 24 hours source operation. Inspection before / after exposure revealed no relevant contamination.

- **EUV Light Extraction Assembly** – Single or *Double bounce mirror assembly with debris mitigated IF module*



LPP Source Meets EIDEC Requirements for Blank Mask Inspection Cleanliness after IF



“We are pleased with the cleanliness we measured on Adlyte’s light source under conditions that replicate a production environment. This meets our requirements for blank mask inspection.”

Hidehiro Watanabe, general manager, **EUVL Infrastructure Development Center (EIDEC)**,

PR 22 October 2014

Summary and Conclusions

- Engineering tool (ALPS II) operated as clean EUV source for actinic inspection over hundreds of hours.

- An EUV pulse-to-pulse stability (σ) of 3% has been achieved with improvements on fuel delivery system and droplet tracking / triggering.

- 3 layer debris mitigation strategy including plasma site, collector and IF.

- Grazing incidence collector integrated in source. Location optimized between deposited tin, ions and emission. First EUV measurements and imaging obtained.

- Successful demonstration of required cleanliness at IF for mask blank inspection.

- On track for long-term tests and commercialization in 2015.

Acknowledgments

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